

**FINAL REPORT TO NASA
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**Title: Application of Thioether for
 Vapor Phase Lubrication**

Background: One of the most immediate applications for vapor phase lubrication is the lubrication of turbine missile bearings operating at 600°F and higher. Thio-ether has a major advantage for this application as it can lubricate both as a liquid at low temperatures and as a vapor at temperatures above 600°F.

Objective: The objective of these studies was to identify the optimal conditions for vapor phase lubrication using Thioether for both sliding and rolling wear. The important variable include;

- (1) The component materials including M50 steel, monel and silicon nitride.
- (2) The vapor concentration and flow rate.
- (3) The temperature in the range of 600°F to 1500°F.
- (4) The loads and rolling and/or sliding speeds.

Test Procedures: Tests included:

(1) Static deposition tests were made using a modified TGA unit to determine deposition rates versus time. The quality of deposition was determined using an Scanning Electron Microscope (SEM). Tests were performed using different substrate materials and vapor concentration over a range of temperatures from 600°F to 2000°F. This tests provided an invaluable screening tool to evaluate the optimal conditions for vapor phase lubrication. In particular the rate data itself provided valuable insight into the mechanism of vapor phase lubrication. The SEM photographs clearly indicate whether a good lubricous deposit was formed. Figure 1 shows two SEM photographs. The upper SEM shows a flaky carbonaceous deposit which would not provide good vapor phase lubrication. The bottom SEM show a deposit showing the characteristic nodular structure indicating the formation of a polymeric deposit. Separate studies in which this deposit was dissolved in boiling chloroform and passed through a high pressure liquid chromatograph showed this deposit has a molecular weight range of 10,000 to 40,000 with an average molecular weight of 30,000. These test would identified the optimal conditions for dynamic wear testing.

(2) Dynamic sliding wear test using the pin on reciprocating wear tester at the Advanced Manufacturing Center at Cleveland State University were made. These tests were performed over a range of loads, temperatures and lubricant concentration as identified under (1). It has been shown that if good lubrication can be obtained under sliding wear, as good or better lubrication can be obtained under rolling wear even at much higher speed and pressures.

(3) Dynamic rolling wear tests were made using the rolling fatigue tester at Wright-Patterson Air Force Base (WPAFB) in Dayton, Ohio. Tests were made at pressures up to 700,000 psi, at speeds of 3600 rpm and for the optimal materials, lubricant concentrations and temperatures identified in (2). The Advanced Manufacturing Center of Cleveland State University and WPAFB have been involved collaborative research since 1991. The work at WPAFB has been funded by the Lubrication Branch of the Aero Propulsion and Power

Directorate under the direction of Brian Berstein and Nelson Forster. Work is planned this summer to test different lubricants including Thio-ether using the rolling contact fatigue tester. Concurrently WPAFB is planning to conduct toxicity studies of the vapors formed from the different lubricants being considered for vapor phase lubrication.

Results: Tests under sliding wear have shown that at very low concentrations (0.2%-0.5% by volume in air), Thio-ether can lubricate metal components up to temperatures of 1400°F with a coefficient of friction below 0.04 and with no wear. Figure 3 shows a run at 900°F made using varying concentrations of thio-ether in a carrier gas of air under sliding wear. A cast iron pin and plate were used in this experiment. The applied load was 370 psi and the sliding speed was 12 cm/s. This figure shows the coefficient of friction as a function of time.

The total run lasted for 180 minutes. As can be seen the coefficient of friction was initially 0.15 and then dropped to 0.03. At a concentration of 0.16ml/h the best results were obtained with a coefficient of 0.01. During the first few minutes the temperature at the interface between the pin and plate heated up due to friction. During this time a lubricous solid coating formed on the plate. Previous studies have shown this to be a solid, polymeric derivative of the Thio-ether formed on interaction with the metal surface at these high temperature. As the run progressed the rate of deposition of the coating and the wear of the coating became equal and the net wear was essentially zero. There was no wear of the metal surfaces. Similar results have been obtained for ceramic materials using TCP. With ceramics, under sliding conditions it is necessary to "activate" the ceramics with a metal ion such as iron or copper. A simple chemical method of activating ceramics is discussed in Patent 5,139,876 issued to Cleveland State University on August 18, 1992.

FUTURE WORK

Application of Thio-ether for Lubrication of Hot Metal Forming Operations

Background: Currently a suspension of graphite in water is used to "lubricate" dies in many metal forming operations in the forging industry. This method provides minimal lubrication, is very costly and produces a very dirty and hazardous work environment.

Preliminary Results: An emulsion of 0.5% phosphazene and 10% alcohol in water was found to be very stable. This emulsion was used to lubricate H13 steel dies forming "D" lugs from billets of 1045 steel. The temperature of the die was approximately 250°F and the temperature of the billets was approximately 2200°F. The dies were sprayed between each pressing by a hand held garden sprayer. Even with this minimal application of emulsion, over thirteen billets were processed with good lubrication as shown by the high quality of the "D" lugs formed. Equally stable emulsions have been formed with Thio-ether and should provide as good or better lubrication of die forging operations.

Objective: The objective of this work would be to find optimal conditions to lubricate forging dies. The variables include;

- material of the die and billet
- friction factor
- type and concentration of the phosphate ester
- method of application of the emulsion or lubricant

Test Procedures: The tests would include:

- (1) Static tests of emulsion stability
- (2) Simple tests in which various materials at different temperatures using different emulsions and concentrations would be sprayed with the lubricant. In these tests the surface would be analyzed using Scanning Electron Microscopy and EDX to determine the nature and quality of the lubrication process.
- (3) Dynamic tests using the 700 ton experimental press owned by CSU and maintained by SIFCO. In these tests an actual forging operation will be analyzed. The equipment will also be fully instrumentated to provide information on stress and die wear. The best lubricants and conditions identified in (1) would be used in these tests. The cost of the testing is \$150/hr including operator labor.
- (4) Final tests would be made using the best results from (2) on a actual forging operation in a forging facility at one of the members of the Forging Network of Ohio.
- (5) Analytical procedure; deform simulations to evaluate important forging parameters (e.g. friction factor).
- (6) Die inspection using CMM and SEM to determine die wear.

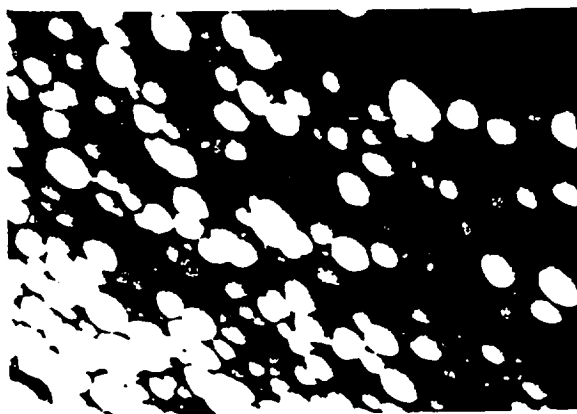


Figure 1. Scanning Electron Microphotographs of Vapor Phase Deposits.

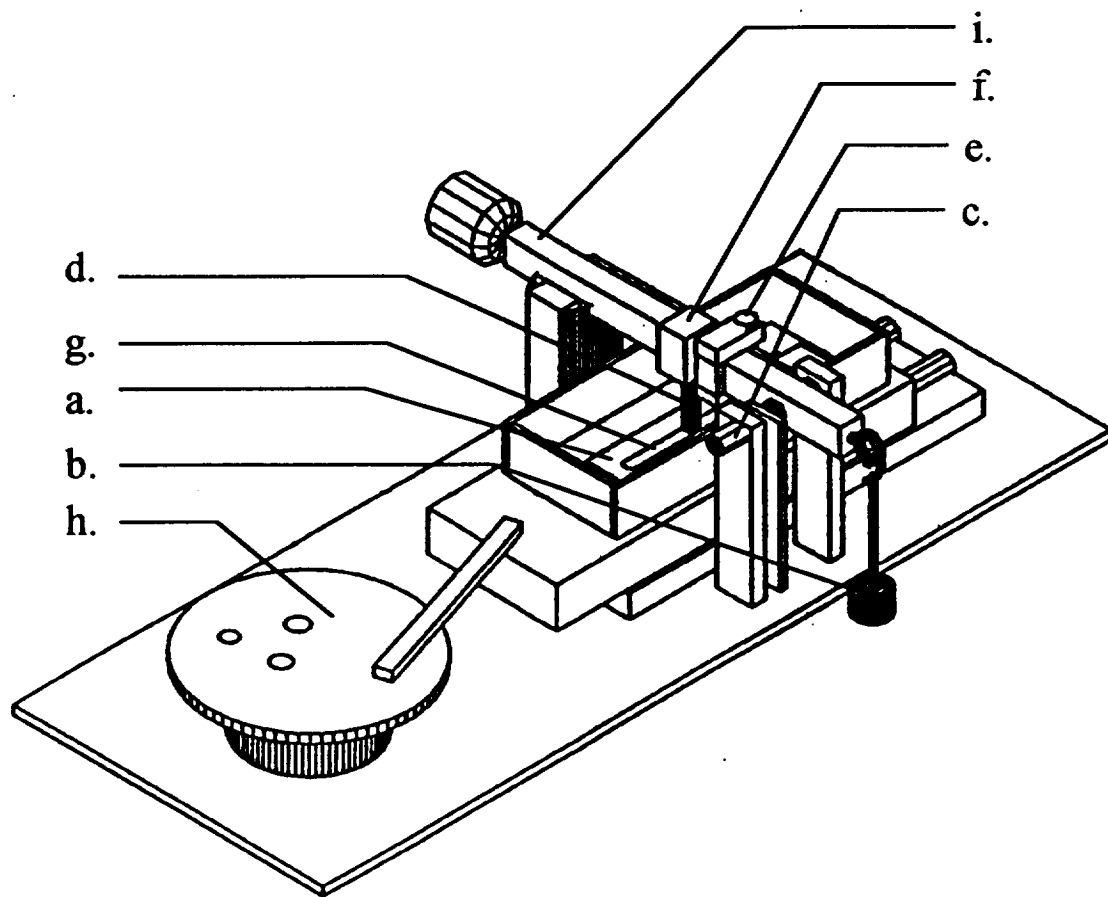


Figure 2

Schematic view of the Universal Wear Tester. a. Plate, b. Weight, c. Friction Transducer, d. Pin, e. Wear Transducer, f. Force Post, g. Wear Track, h. Variable Speed Drive, i. Lever Arm

Thioether on Cast Iron
 Plate Temp: 500 C
 Vapor Temp: 400 C
 Load: 4 kg

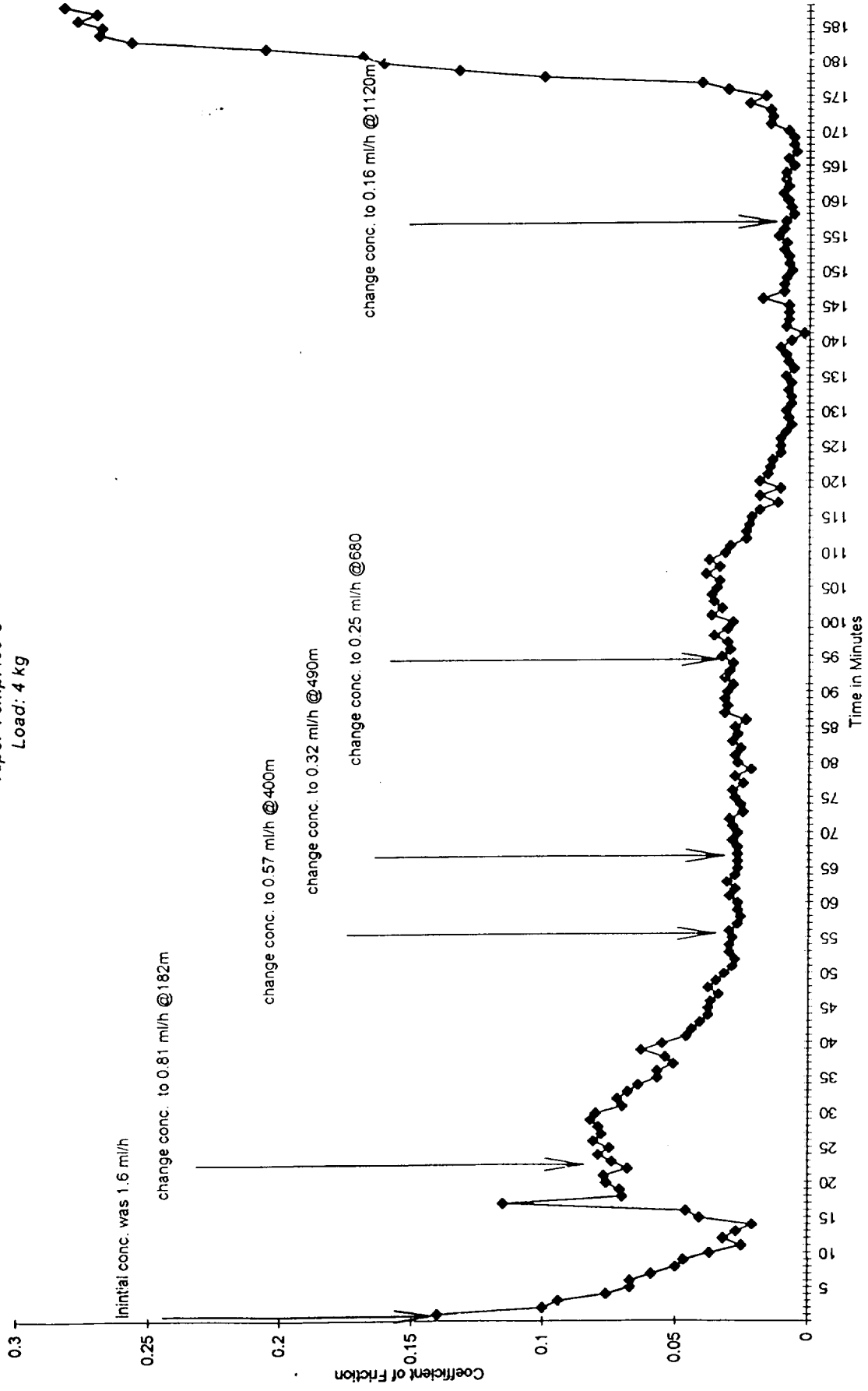


Figure 3. Wear Test Data for Concentration Experiment with Thioether.